

The study of massive stars with $50 M_{\odot}$ initial mass at different evolutionary stages

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Abstract. We will present results of studies of several massive stars at different evolutionary stages, but with similar values of the initial mass: O-supergiants belonging to association Cyg OB2, unique LBV/post-LBV – Romano’s star and two Wolf-Rayet stars – WR156 and FSZ35. All these stars have similar initial mass of about $50 M_{\odot}$. It allows us to consider them a single star at different moments of life, and it gives an opportunity to track changes in the physical parameters (such as effective temperature, luminosity, mass loss rate, wind velocity) and chemical abundances during the life of a massive star. It is important to test the current evolution theories of such objects.

1. Introduction

According to modern concepts the evolution of massive stars occurs as following: during hydrogen burning in the core massive stars shift to the right on the Hertzsprung-Russell (H-R) diagram. OB-stars transform to red supergiants (RSG, $8M_{\odot} < M_* < 40M_{\odot}$) or to luminous blue variables (LBVs, $40M_{\odot} < M_* < 60M_{\odot}$) (Meynet et al. 2011). After that more massive stars ($M_* > 30M_{\odot}$) move again to the left part of H-R diagram and across the phase of Wolf-Rayet stars (WR), which is final stage before supernova (SN) explosion. For less massive stars ($8M_{\odot} < M_* < 30M_{\odot}$) the progenitors of SN are directly RSG.

Numerical modeling of the evolution of massive stars started in 90s. Due to a significant increase in computer processing power, modern codes for the calculation of stellar evolution have become reliable tools for astrophysical research – for estimation of stellar ages, initial mass, chemical composition, etc. Modern stellar evolution codes generally describe well the locations of observed variety of the massive stars – as well as RSG, LBV and WR – on H-R diagram.

However there are still a number of contentious issues in the theory of massive stars’ evolution. For further development of the theory it is necessary to compare theoretical predictions with observations, with the parameters of actually observed massive stars. One of the important tasks of modern stellar astrophysics is to determine the stars’ parameters on short stages of evolution such as LBVs, yellow hypergiants, blue supergiants, WR stars, and during the transitions between them.

Here we present brief description of an evolution of massive star with $50\text{--}60 M_{\odot}$ mass by means of studying various objects with such masses on different stages of their lives.

2. Stars with 50-60 M_{\odot} initial mass

O supergiants

For consideration stage of O-supergiant was selected the stars from the association Cyg OB2 – #7 (O3If_{*}) and #11 (O5.5Ifc)¹.

Cyg OB2 #7 is one of the hottest stars in our Galaxy. As result of our modeling we found that in the spectrum of the star there are some lines whose are not described within the framework of single model with simple velocity law. For fitting strong emission line $H\alpha$ and absorption NIV and CIV lines is necessary or to involve considerations that wind is nonspherical, or to use more complicated velocity law.

Cyg OB2 #11 is classified as Ofc supergiant (Walborn et al. 2010). Our results suggest that its physical parameters are close to the ones of “normal” O-supergiants with no strong carbon emission. In Cyg OB2 #11 the nitrogen abundance is lower than the one for other “normal” O stars, while the carbon abundance is nearly solar. Therefore we may conclude that the mixing in atmospheres of Ofc stars that transports the products of CNO cycle from the core towards the stellar surface is somewhat damped.

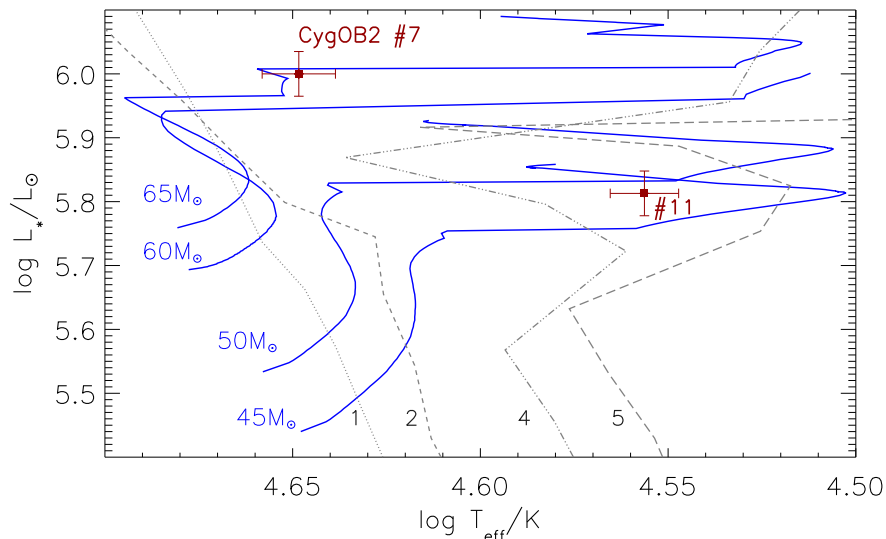


Figure 1. The locations of Cyg OB2 #7 and #11 in the H-R diagram. The evolutionary tracks and the stellar isochrones are taken from the Geneva library.

Romano’s star

Romano’s star (M33/V532 or GR290) is a famous variable star, which is now classified as LBV/post-LBV star and shows late-WN spectrum, and is very important for our understanding of evolution of massive stars in general.

Our analysis of nine most representative spectra, obtained between October 2002 and December 2014, when the star displayed an ample range of variation in visual luminosity, shows that the bolometric luminosity of GR 290 is variable, it is higher

¹Results was published in Maryeva et al. (2013b) and Maryeva et al. (2014)

during the phases of greater optical brightness. It confirms the hypothesis from earlier works by Polcaro et al. (2011) and Maryeva & Abolmasov (2012a). We also found that the structure of the stellar wind significantly changes, being much denser and slower during the eruption in 2005, while during the minimum of brightness the wind structure is fairly similar to the one of typical WN8h stars.

Figure 2 shows the recent path of GR 290 in the H-R diagram during two successive luminosity cycles. GR 290 sits on the evolutionary track of a $\approx 50 M_{\odot}$ star. In maximum of brightness ($V=17^m$, Feb. 2005) the star is located on the LBV minimum instability strip and it moves to WR region in the minimum of brightness. GR 290 is the first star which demonstrated the transition from the instability strip to WR region (Maryeva 2014; Polcaro et al. 2016). The high effective temperature and WNL-type spectrum place the star after the low temperature loop of the evolutionary tracks which is thought to be occupied by the LBV stars. Estimated chemical abundances for atmosphere of GR 290 show that the star is younger than WN8h stars (Polcaro et al. 2016). Combining the results of numerical modeling with data of photometric and spectral monitoring we may conclude that we observed GR 290 in very rare evolutionary phase – post-LBV.

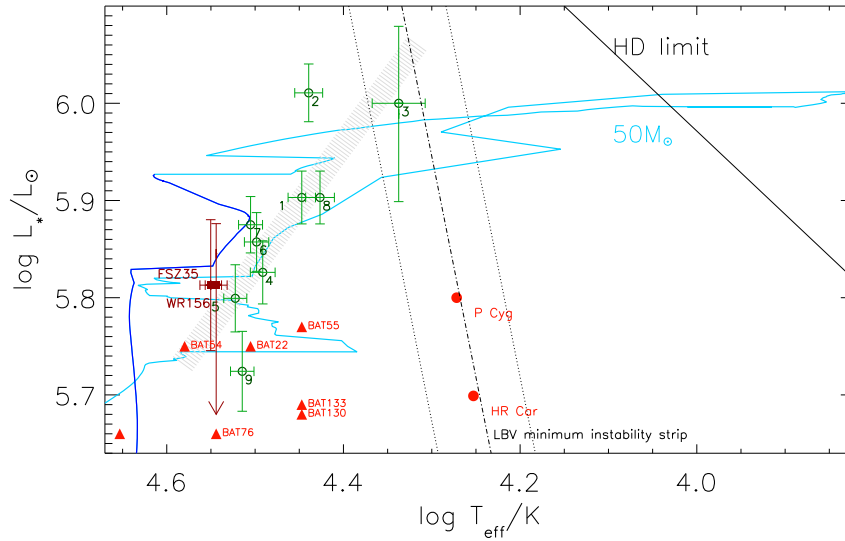


Figure 2. Position of GR 290 in the H-R diagram in 2002 – 2014 years. HD limit is Humphreys-Davidson limit (Humphreys & Davidson 1994). Numbers correspond to the dates of observations: 1 – Oct 2002, 2 – Feb 2003, 3 – Jan 2005, 4 – Sep 2006, 5 – Oct 2007, 6 – Dec 2008, 7 – Oct 2009, 8 – Dec 2010, 9 – Aug 2014. Filled squares mark the positions of FSZ35 and WR156.

Wolf-Rayet stars

Next evolutionary state after LBV phase is the WR star of nitrogen sequence (WN). We consider WN state using two stars of WN8 subtype: FSZ35 which is located in M33 galaxy (Maryeva & Abolmasov 2012b) and WR156 – in our Galaxy (Maryeva et al. 2013a). Performed modeling allows both to determine parameters of the stars as well as to refine the evolutionary state of GR 290.

Table 1. Derived properties of studied stars. $R_{2/3}$ is radius where the Rosseland optical depth is equal to 2/3, T_{eff} is effective temperature at $R_{2/3}$, \dot{M}_{cl} is mass loss rate, X_H the mass fractions of hydrogen.

Star	V [mag]	Sp. type	L_* , 10^5 [L_\odot]	\dot{M}_{cl} , 10^{-5} [$M_\odot \text{yr}^{-1}$]	T_{eff} [kK]	$R_{2/3}$ [R_\odot]	V_∞ [km s^{-1}]	X_H [%]
Cyg OB2 #7	10.55	O3If _*	10	0.15	43.2	18	3250	50
Cyg OB2 #11	10.03	O5.5Ifc	6.5	0.17	36.0	20.7	2200	82
GR 290 (Jan 2005)	17.24	WN11h	12	4.2	23.7	65	200	29.5
GR 290 (Aug 2014)	18.74	WN8h	5.3	1.7	32.8	23	400	29.5
WR156	11.01	WN8h	6.5	1.5	35	22	550	30
FSZ35	18.78	WN8h	6.5	2.4	35.5	21.3	750	17

3. Discussion

In this work we studied different stars having similar initial masses in order to track the stellar evolution at different moments of stellar life. The comparison of stellar parameters raise the following questions:

- The star Cyg OB2 #7 has the evidences of non-spherical wind structure – how does this feature influence the consecutive evolution of the star?
- In star Cyg OB2 #11 we see the nitrogen abundance anomaly – how does it evolve, will it disappear on the LBV stage when the star changes significantly and loses its envelopes? and how will its remains manifest itself on the following WR stage?

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